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EXPERIMENTS IN DESTABILIZING SOILS WITH CHEMICALS

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

November 1956

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Waterways Experiment Station
CORPS OF ENGINEERS, U. S. ARMY
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PREFACE

A letter from the Office, Chief of Engineers, to the Director, Waterways Experiment Station, dated 2 August 1951, subject "Destabilizing Tactics," authorized preparation of a plan of test for conducting field tests with bentonite. Later, a conference between Messrs. R. R. Philippe and W. J. New of the Office, Chief of Engineers, and Messrs. W. J. Turnbull and C. R. Foster of the Waterways Experiment Station on 13 and 14 August 1951 resulted in verbal authorization for the Waterways Experiment Station to conduct the tests presented herein.

The tests were conducted during the period 14 August-20 September 1951. Personnel of the Soils Division, Waterways Experiment Station, actively connected with the investigations were Messrs. W. J. Turnbull, C. R. Foster, O. B. Ray, E. C. Meredith, and A. B. Thompson. This report was prepared by Mr. Thompson.

CONTENTS

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SUMMARY

The tests described herein were conducted to determine the effectiveness of bentonite as an agent for reducing the usefulness of airfield and roadway surfaces. Small-scale pilot tests were conducted on flexible pavement and turf to develop methods of applying the bentonite, to select the type of granulated bentonite best suited for the purpose, and to determine quantities to be used in full-scale tests. Laboratory tests were then performed on blends of bentonite and deliquescent materials to determine the ability of the mixture to absorb moisture from the air and become plastic; however, not enough moisture was absorbed to produce stickiness. Mixtures of a lean-clay soil and bentonite were also tested and it was found that the bentonite admixture increased the plasticity index of the soil.

For the full-scale tests, existing surfaces of flexible pavement, bare soil, and turf were treated with varying quantities of granulated bentonite. The material was moistened and its effect on movement of vehicles was determined by traffic and skid tests. The tests showed that bentonite, applied as thickly as considered reasonably possible for a large area, will not destabilize flexible pavement, bare soil, or turf sufficiently to immobilize a light tank, a 2-1/2-ton truck, or a 1/2-ton truck. Limited tests made of Aqua Gel produced the same results. Removal or neutralization of the bentonite was attempted by different methods, and washing or shoveling was found to effectively remove the chemical.

EXPERIMENTS IN DESTABILIZING SOILS WITH CHEMICALS

PART I: INTRODUCTION

Purpose and Scope of Tests

1. The experiments reported herein were conducted to determine the effectiveness of bentonite as an agent for reducing the usefulness of airfield and roadway surfaces. Bentonite is a highly plastic clay composed largely of the clay mineral montmorillonite, which is noted for its swelling property when saturated. It was thought that application of such a material to paved or unpaved surfaces might make such surfaces too slippery for use by wheeled and tracked vehicles and by aircraft.

2. Another chemical, Aqua Gel, was also subjected to limited tests for the same purpose. Aqua Gel is a drilling mud consisting of pure Wyoming bentonite, and is distributed by the Baroid Division, National Lead Company.

3. The test program for the bentonite consisted of pilot tests, laboratory tests of bentonite and several deliquescent materials, and full-scale traffic tests of bentonite-coated test sections.

Test Material

4. Inspection of samples of commercially powdered bentonite indicated that the powdered material was too fine to be applied in any reasonable manner and that a more granular material would be desirable. Since the desired gradation was not known, three gradations of bentonite were obtained from the American Colloid Company, Chicago, Illinois, through their shipping point at Aberdeen, Mississippi. The trade name of these materials is Volclay, and they were mined and processed in Wyoming. The Volclay has an average dry density of 70 lb per cu ft when packaged in bags for shipment. The gradations of the three types of Volclay procured were as follows:

Present Nomenclature	Old Nomenclature	Sieve Size	Per Cent Passing
Volclay (crusher run)	4 mesh, "dried and crushed"	3/8-in.	100.0
		No. 4	99.8
		8	94.3
		30	5.1
		50	1.5
		100	0.9
		200	0.6
KWK Volclay	KWK 33	No. 8	100.0
		30	72.8
		50	13.9
		100	3.0
		200	1.2
MX 80 Volclay	KWK 80	No. 8	100.0
		30	99.9
		50	88.2
		100	48.0
		200	15.9

PART II: PILOT TESTS

5. Since no information was available as to what type of bentonite would be most suitable for traffic test purposes, or how and in what quantities the material should be applied, a series of pilot tests on small panels of flexible pavement and turf was conducted to provide this information.

Test Panels and Tests

Flexible pavement

6. Seven test panels, each 4 sq yd in area, were placed on an existing section of flexible pavement. The type and thickness of the bentonite on these test panels were as follows:

Panel No.	Type of Bentonite	Thickness, in.
1	KWK Volclay	1/16 (3.3 lb per sq yd)
2	Volclay (crusher run)	1/8 (6.6 lb per sq yd)
3	MX 80 Volclay	1/8 (6.6 lb per sq yd)
4	KWK Volclay	1/8 (6.6 lb per sq yd)
5.	Volclay (crusher run)	1/4 (13.2 lb per sq yd)
6	MX 80 Volclay	1/4 (13.2 lb per sq yd)
7	KWK Volclay	1/4 (13.2 lb per sq yd)

7. Each of the panels was prepared by weighing out the desired quantity of bentonite and spreading it, with a wooden templet, as uniformly as possible over the area. It was found on panel 1 that 3.3 lb per sq yd (1/16 in. thick) did not provide complete coverage. Coverage was satisfactory with all three materials when applied at the rate of 6.6 lb per sq yd (1/8 in. thick) or more; consequently, this was concluded to be the minimum thickness that would provide adequate coverage. The coarser material (crusher-run Volclay) was easiest to spread by templet, the finer materials becoming more difficult to spread uniformly with increasing fineness.

8. All, or part of each of the flexible pavement test panels was

moistened to determine the degree of swelling and the ability of each gradation of bentonite to absorb water. Water was applied with a sprinkler can when the pavement temperature was about 140 F. About 200% water, based on the dry weight of the bentonite, was applied to the KWK Volclay in panel 1. The material appeared to be well moistened and swelled to approximately double the original 1/16-in. thickness. The condition of the KWK Volclay after drying for 24 hr is shown on fig. 1. It may be noted that as the material dried, it curled up, lost most of its slipperiness, and decreased in volume leaving a large portion of the pavement uncovered. Half of panel 2 was moistened to a water content of 200%. The crusher-run Volclay in panel 2 absorbed water readily and swelled from 1/8 to 1/4 in. in thickness. After 24 hr, cracking and shrinking had occurred similar to that in panel 1, but not to as great an extent. Half of panel 3 was also moistened, but it would absorb only 135% water at one time. The moistened MX 80 Volclay of

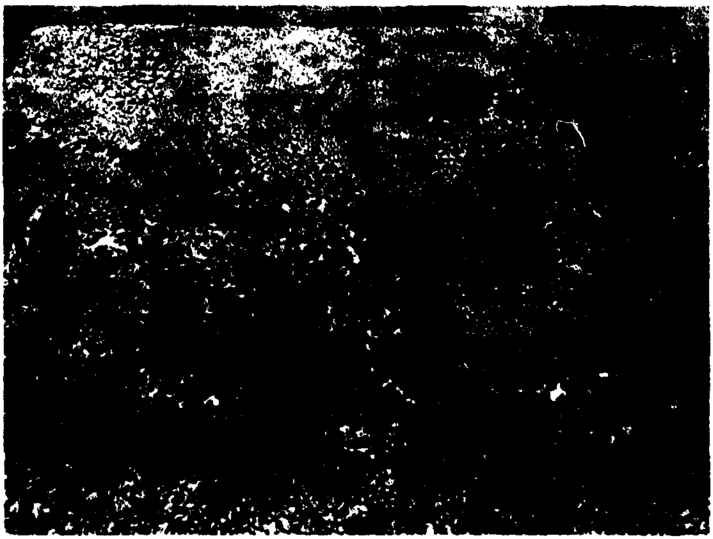


Fig. 1. KWK Volclay on pavement panel 1 after wetting and allowing to dry for 24 hr

panel 3 had shrunk excessively after 24 hr and was found to have been moistened to less than half of the 1/8-in. depth. The KWK Volclay in panel 4 absorbed about 180% water. After 24 hr, excessive shrinkage had occurred leaving portions of the pavement exposed. However, some areas in the panel had not been moistened to the full 1/8-in. depth. Similar trends were observed on panels 5, 6, and 7 where the depth of dry material was 1/4 in.

Turf

9. One additional test panel was prepared on turf. The crusher-run Volclay was applied with a small fertilizer spreader to an average thickness of about 1/8 in. (6.6 lb per sq yd). No conclusions were reached as to thickness requirements on turf, but it was noted that 24 hr after the area had been moistened the bentonite remained slippery and had not cracked and dried out.

Test Results

10. These pilot tests indicated that reducing the usefulness of a pavement or roadway with bentonite would be a difficult problem, particularly in dry and hot weather. The appearance of the test panels after a 0.5-in. rain indicated that some success might be attained in wet weather. As long as the moisture was retained, the bentonite on panel 1, which was only 1/16 in. thick, swelled to the extent that coverage was complete and the thickness increased to about 3/16 in.

11. Observations of the test panels indicated that crusher-run Volclay had the most satisfactory gradation and should be used in the test sections proposed for traffic tests. It was believed that a thickness of 1/16 in. might prove to be adequate when saturated, and that a 1/8-in. thickness should definitely prove adequate when saturated. It was not believed that a greater thickness (such as 1/4 in.) could be applied over a large area in any practical manner. Therefore, thicknesses of 1/8 and 1/16 in. were selected for the traffic test sections. A third thickness of about 1/32 in. (1.65 lb per sq yd) was also included to determine if less than complete coverage would produce the desired results.

12. Two methods of removing the bentonite from the pilot test panels were tried. The material could be easily and completely removed by washing with a medium-pressure hose. It could also be removed satisfactorily from the paved surfaces with a shovel.

PART III: LABORATORY TESTS

Effect of Deliquescent Materials

13. Since retention of moisture appeared to be important to the satisfactory performance of bentonite, laboratory tests were made on the MX 80 Volclay admixed with two deliquescent materials at five different percentages, varying from 2 to 10% by dry weight. The deliquescent materials used consisted of calcium chloride and sodium hydroxide. The latter chemical proved least effective for collecting moisture; therefore, further tests with it were discontinued. On the basis of information resulting from these tests, the laboratory testing program was extended to include, besides calcium chloride, six other deliquescent chemicals consisting of magnesium chloride, zinc chloride, manganese sulfate, potassium hydroxide, phosphorus pentoxide, and phosphorus pentachloride. It was also decided to use only two percentages of the deliquescent materials and admix them with all three types of bentonite. After the admixture was made, the material was placed in a room where the relative humidity was about 90%. The samples were weighed at 24-hr intervals to check the amount of absorbed moisture. This process was continued for 10-15 days on all materials except manganese sulfate. Tests on manganese sulfate were stopped after three days as it had absorbed only a negligible quantity of moisture.

14. Results of these laboratory tests are summarized in table 1. After 11 days, the greatest absorption of moisture was in the KWK Volclay containing 10% calcium chloride. Calcium chloride, magnesium chloride, zinc chloride, and phosphorus pentoxide seemed to be the most effective of the deliquescent materials. As the per cent admixture increased in the bentonite, the per cent moisture absorbed for a given time interval likewise increased. For a given deliquescent material, the three types of bentonite (Volclays) showed very little difference in the percentage of moisture absorbed. Plate 1 shows graphically the increase in per cent moisture absorbed for 5 and 10% of each of the admixtures. It will be noted from these plots that the absorbed moisture gradually increased with

time up to a certain percentage and then became relatively constant. The greatest amount of absorbed moisture was only slightly above 50%. Since more than 100% moisture is required to make the bentonite slippery, it appears that none of the deliquescent agents can take enough moisture from the air to produce a slippery condition.

Effect of Bentonite on Plasticity Index of Soil

15. Atterberg limits tests were made on a lean-clay (CL) soil mixed with 1, 5, and 10% MX 80 Volclay. Plate 2 shows the effect that the addition of bentonite had on the Atterberg limits of the soil. From this chart it may be noted that the liquid limit increased as the percentage of bentonite increased, and that the plastic limit was lowered approximately 2 points with the 5 or 10% admixtures of bentonite. The plasticity index increased from 17.1 to 54.9 with the 10% admixture of bentonite.

Suspension and Viscosity Tests of Other Bentonites

16. These comparative laboratory tests were conducted on the Volclay (crusher run) bentonite and on four other kinds of bentonite, namely, (a) 200-mesh Volclay (high swelling); (b) foundry Volclay; (c) Sykes Terminal Warehouse Volclay; and (d) Panther Creek southern bentonite, for the purpose of determining whether any of the latter four might possess qualities or characteristics that would make them superior to Volclay (crusher run) in the destabilization of surfaces. The 200-mesh Volclay (high swelling) appeared slightly superior to the other three. However, its behavior was so similar to that of the crusher-run Volclay that it did not merit additional field testing.

PART IV. TRAFFIC TESTS

Test Areas

17. Three test lanes, each 135 ft long by 15 ft wide, were laid out: one on flexible pavement, one on bare soil, and one on turf. Each test lane was divided into three 45-ft sections. Section 1 was coated with 6.6 lb per sq yd of bentonite, providing a nominal thickness of 1/8 in.; section 2 with 3.3 lb per sq yd of bentonite, providing a nominal thickness of 1/16 in.; section 3 with 1.65 lb per sq yd of bentonite, providing a nominal thickness of 1/32 in. A typical layout of a traffic test lane is shown on plate 3.

Placement of Bentonite

18. Based on the results of the pilot and laboratory tests, the crusher-run Volclay was used for the field tests. The material was placed by hand on the pavement and bare soil sections and smoothed to the desired thickness using a square-point shovel. In the pavement lane, section 1 was completely covered (see fig. 2) and section 2 was nearly

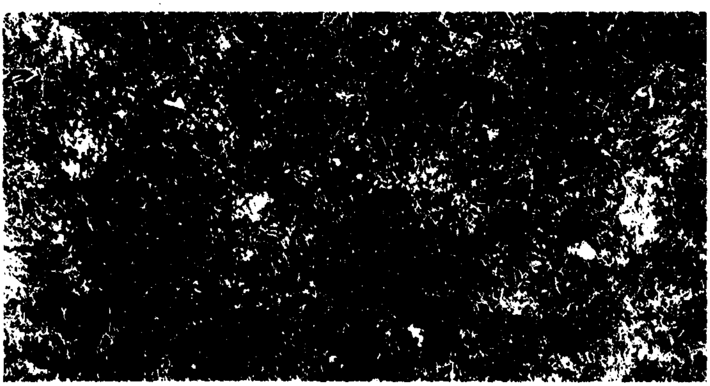


Fig. 2. Close-up of section 1 (1/8 in. thick) of the turf lane after placement of the bentonite

covered, but section 3 had several bare places which could not be completely worked out. Uniform spreading could not be achieved by the hand method on the turf lane; therefore, a small fertilizer spreader was used to distribute the bentonite to an even thickness. No difficulty was encountered in spreading the material by this method.

Equipment and Procedures

19. The following vehicles were used for the traffic tests:

a. Light tank (M24) weighing approximately 37,000 lb and equipped with T72 steel tracks that give an average contact pressure of 11.3 psi.

b. Two-and-one-half ton, 6x6 truck equipped with 10.50x18 high-flotation tires on all wheels, inflated to 45 psi. The empty weight was approximately 11,000 lb.

c. One-half ton pickup equipped with 6.00x16 tires, inflated to 32 psi. The empty weight was approximately 3300 lb.

20. A 6000- and a 40,000-lb-capacity, electric recording-type dynamometer, developed by the Waterways Experiment Station, were used to obtain drawbar measurements on towed vehicles. The dynamometers were used with a Brush BL-320 universal analyzer and a Brush direct-inking oscillograph for recording the measurements.

21. Measurements of resistance to skidding were made in the test lanes with each test vehicle before traffic was applied. The wheels or tracks were locked and the vehicle towed across all three sections. The force required to keep the vehicle moving was measured. After these drawbar measurements were obtained, braking tests were made with each vehicle at speeds of 10 mph, or better. The procedure used during braking tests was to drive the vehicle onto the section at the desired speed, set the brakes, and measure the distance of skid. On completion of these tests, traffic was applied by running the vehicles back and forth on the sections, the vehicle being moved over the width of a tire or tread after each pass. Observations were made of the maneuverability of each vehicle. The tank preceded the truck in each test lane except the turf lane.

Test Results

Flexible pavement lane

22. Preparation of test sections. A light rain occurred immediately after the bentonite was placed on this lane. It was noted that the rain did not thoroughly moisten even section 3 (1/32 in. thick); however, it did cause this section to be nearly covered after the material had swelled. A heavy rain began at 5:00 AM the next day and continued until about 11:00 AM. A rain gage located on the Waterways Experiment Station reservation showed that 2 in. of rain fell during these hours. Practically all of the bentonite on section 3 was washed away by 11:00 AM (fig. 3). About half of the material on section 2 (1/16 in. thick) had also washed away. The material on section 1 (1/8 in. thick) had swelled to about 3/4 in. thick and free water was standing on the section (fig. 3). A milky-colored fluid was also draining from this section. Samples taken of the saturated bentonite showed an average moisture content of 660%.

Fig. 3. Pavement lane with section 1 in foreground and section 3, badly eroded, in background

23. Observations made about 20 hr after the rain showed the material to be drying out, causing shrinkage and large cracks to appear. Most of the bentonite was still intact on sections 1 and 2; therefore, it was decided to sprinkle the section with water and apply traffic with the 2-1/2-ton truck.

24. Tests. Measurements of the force required to tow the 2-1/2-ton truck with wheels locked, made prior to traffic, showed 3400 lb on section 1 and 3550 lb on section 2. This indicates that variations in the thickness of bentonite apparently had a very slight effect. After the vehicle had been pulled through the sections, a very thin film of bentonite adhered to the pavement where the tires had skidded on section 1, but no film was noted on section 2. In the braking tests, the 2-1/2-ton truck was brought to a stop from a speed of 10 mph in a distance of 11 ft, which is about the same distance required to stop on nontreated pavement. When the brakes were applied, the bentonite was shoved to the front and side of the tires, leaving clean pavement. The 1/2-ton truck, when tested at a speed of 20 mph, required 15 ft to stop. This was also about the same distance that would have been required for a stop on clean pavement. When traffic was applied, the bentonite rutted and shoved out from under the tires, leaving bare pavement; therefore, no difficulty was encountered in maneuvering either of the trucks. The condition of section 1 after traffic is shown on fig. 4.

25. The bentonite was removed from the pavement test lane after the truck traffic by use of a low-pressure water hose and shovels. The area was then rebuilt in the same manner as before. The bentonite was sprinkled with a low-pressure hose until free water was standing, allowed to soak, and then sprinkled again until the material was saturated. The area after watering and prior to traffic is shown on fig. 5.

26. Measurements made with the M24 light tank showed that the force required to keep the vehicle moving when the tracks were locked was as follows: section 1, 11,010 lb; section 2, 11,560 lb; and section 3, 11,920 lb. Thus the force required to keep the vehicle moving increased slightly as the thickness of bentonite decreased. Braking tests made at 10-12 mph showed that the tank could be brought to an immediate stop

Fig. 4. Section 1 of pavement lane after traffic

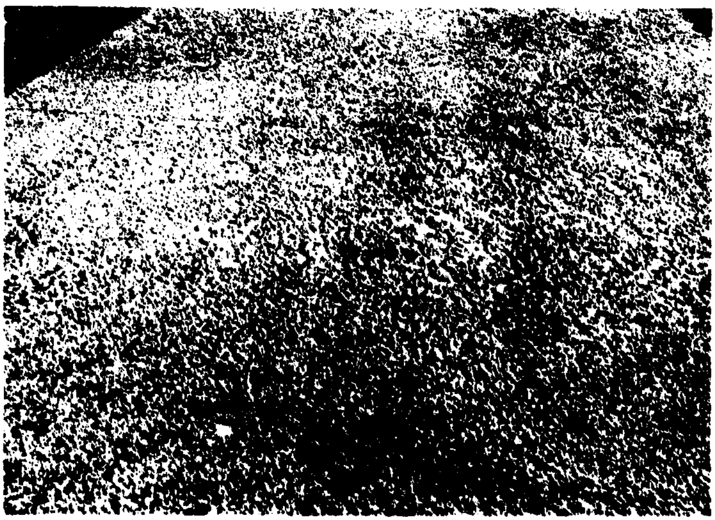


Fig. 5. Section 3 of pavement lane in foreground, after watering and prior to traffic

without skidding when the brakes were applied suddenly. No difficulty was encountered in maneuvering the vehicle on any of the three sections in the pavement test lane. When traffic was applied, the bentonite was displaced, leaving bare pavement showing at the grouser marks. Slight slipping of the track occurred when the tank was turned on the bentonite; however, this had little or no effect on its maneuverability.

27. Additional tests were made with the two trucks after traffic with the tank. The 1/2-ton truck did not maneuver as easily this time; however, it was far from being immobilized. A distance of 25-40 ft was required to bring this vehicle to a stop from a speed of 20 mph. The 2-1/2-ton truck did not maneuver as easily as it had on the first test area; however, it was still maneuverable. Braking tests showed considerable variance. About 100 ft was required to bring the truck to a stop from a speed of 20 mph, whereas on the first test area 11 ft was required to bring the truck to a stop from a speed of 10 mph. The condition of the test area after traffic is shown on fig. 6.

Fig. 6. Pavement lane after traffic

Bare soil lane

28. Preparation of test sections. The 2-in. rain referred to in paragraph 22 also fell after the bentonite had been placed on this section. Practically the same results occurred here, except no free water was noted on the bentonite. Samples taken from section 1 showed the bentonite to have an average moisture content of 445%. The soil was wet for a depth of about 1 in. underneath the bentonite. After 48 hours, the bentonite had dried and cracked considerably; it was then watered with a low-pressure hose, but would not reswell. Most of the water went into the cracks causing the subgrade to become wet and soft. In view of these conditions the old bentonite was removed and new material placed in the same manner as before. Water was added three times before the bentonite became saturated.

29. Tests. Measurements of the force required to tow the tank and 2-1/2-ton truck with tracks and wheels locked were made prior to traffic. The force required to keep the tank moving was as follows: section 1, 11,400 lb; section 2, 12,200 lb; and section 3, 12,830 lb. These forces are slightly higher than those measured during comparable tests on the pavement lane. The tank track pushed the bentonite aside, leaving a clean path in the soil. The force required to keep the truck moving was as follows: section 1, 1930 lb; section 2, 2500 lb; and section 3, 2540 lb. These forces are considerably less than those measured during comparable tests on pavement. The excess bentonite was shoved to the side when the tires skidded across the sections. However, a light film of the material was left on the soil which apparently was sufficient to reduce the force required to tow the truck below that which would have been required to tow it on bare soil.

30. The M24 light tank encountered no difficulty in maneuvering in the traffic tests. The track cut through the bentonite and into the soil causing the bentonite and soil to blend. The tank maneuvered about as easily as it would have on soil. When the brakes were applied at a speed of 12 mph, the tank stopped without the tracks slipping; in fact, the tracks cut into the soil down to the dry material about 1 in. below the surface.

31. The 2-1/2-ton truck could maneuver easily on all of the three sections of the bare soil traffic lane. The bentonite shoved from under the tires leaving bare soil exposed. A distance of 50 ft was required to stop the truck from a speed of 16 mph.

Turf lane

32. The 2-1/2-ton truck was tested first on this area. Dynamometer measurements showed that the force required to keep the truck moving was as follows: section 1, 1000 lb; section 2, 1010 lb; and section 3, 1120 lb. These forces are less than those measured during comparable tests on both the pavement and bare soil lanes. The tires pushed the bentonite aside, somewhat as on the other two lanes. However, the displacement was not as complete in this case and the tracks left by the truck were quite slippery. When measurements of the required towing force were made on the tank, the tracks tore up the turf to some extent, but more of the slipperiness remained in the track made by the tank than remained at the other two traffic lanes. The force required to keep the tank moving was as follows: section 1, 5560 lb; section 2, 6020 lb; and section 3, 6980 lb.

33. Neither of the vehicles had much difficulty in maneuvering on any of the three sections in this traffic lane; however, the truck had more difficulty than the tank. There was a 2% lateral slope in this lane which caused the truck to slip to the side. The tracks on the tank cut into the soil and did not slip to the side. The tires had a tendency to spin on section 1, but not to such an extent that the movement of the truck was hampered. This tendency of the tires to spin was not noted on the other lanes. Some of the bentonite was shoved to the side by the tires in the same manner as had occurred on the other two lanes. The condition of the turf lane after traffic is shown on fig. 7.

34. At a speed of 12 mph the tracks of the tank slipped 2 ft when the brakes were applied on section 1 of the turf lane; but no slippage occurred on sections 2 and 3. On section 2 when the brakes of the truck were applied at a speed of 18 mph, a distance of 63 ft was required to bring the truck to a stop. During this test the truck was headed toward section 1 and the skid extended approximately halfway into section 1.

Fig. 7. Turf lane after traffic (1/8-in. section in foreground)

The truck was then turned around and the brakes applied on section 1 at a speed of 20 mph. A distance of 78 ft was required to stop the vehicle. This area was allowed to dry for two days then again tested with the truck. No evidence of slipperiness remained and the truck maneuvered as easily as on natural turf.

Tests with Aqua Gel

35. An additional experimental test section was prepared using Aqua Gel to see if its effects would be any different from that of the Volclay. An area 27 ft by 10 ft was used for this test. The material was placed to a thickness of 1/16 in. or at a rate of 3.3 lb per sq yd. Water was added by low-pressure hose three times before the material became saturated. The 2-1/2-ton truck was used to apply traffic on this test lane. The behavior of the Aqua Gel under traffic was so similar to

that of the Volclay that no resistance measurements or braking tests were made. The material was shoved to the sides of the tires, leaving a bare pavement and, therefore, the vehicle had no difficulty in maneuvering. There were no indications of a film of this material sticking to the pavement in the tire path.

PART V: CONCLUSIONS

36. Based on results of tests presented in this report, the following conclusions are drawn:

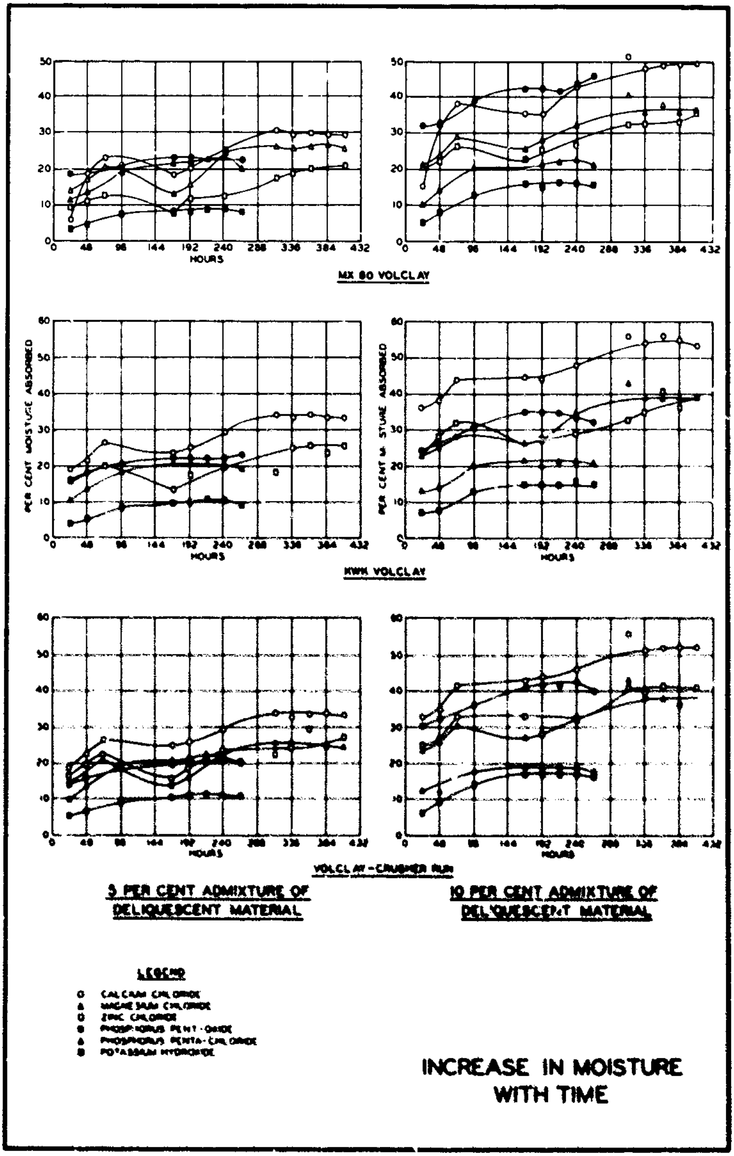
- a. Bentonite mixed with a deliquescent material will not absorb enough moisture to become sticky.
- b. Bentonite will increase the plasticity index of a lean-clay soil.
- c. Bentonite placed in thicknesses of 1/32, 1/16, and 1/8 in. over turf, bare soil, or flexible pavement will not immobilize an M24 light tank, 2-1/2-ton truck, or a 1/2-ton truck.
- d. Aqua Gel reacted in the same manner as Volclay when subjected to traffic.
- e. Bentonite can be removed from a pavement readily by washing or shoveling.

Table 1

Percentages of Moisture Absorbed by Bentonite Samples in Laboratory Tests

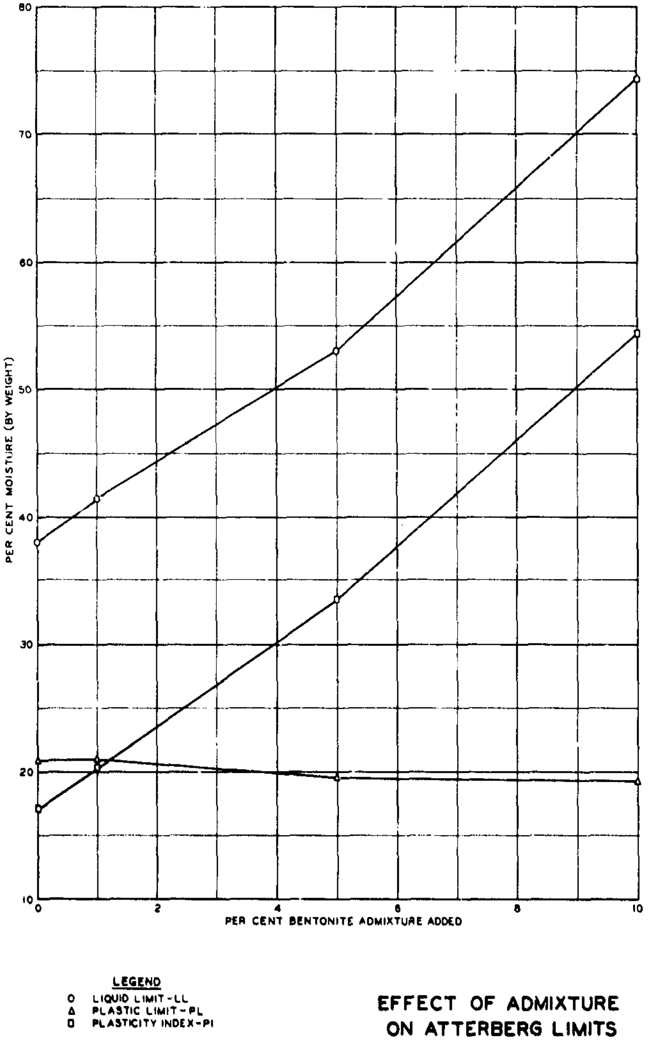
Type of Volclay	Type of Deliquescent	Admix.* %	Moisture Content (Per Cent by Weight) Absorbed in Hours Shown																						
			24	48	72	96	120	144	168	192	216	240	264	288	312	336	360	384	408	432	456	480	504	528	552
MX 80	Calcium chloride	2.0	3.8	1.3			5.5	7.1	4.4	11.1	13.3				----	----		----			----	----	----	----	----
	$CaCl_2$	4.0	4.9	2.7			6.9	9.7	5.3	15.5	19.2				13.5	15.9		21.2			25.9	25.9	26.1	25.0	24.3
		6.0	6.4	4.2			9.9	13.9	7.9	20.8	26.3				22.7	24.3		29.6			35.5	33.3	33.8	33.8	34.2
		8.0	8.8	5.7			13.7	18.1	11.5	25.8	32.2				29.3	30.2		36.3			43.2	41.6	42.3	41.0	41.0
		10.0	12.1	7.3			17.8	22.6	15.4	31.9	38.2				35.6	35.6		42.9			51.6	48.1	48.8	49.2	49.2
MX 80	Sodium hydroxide	2.0	1.8	0.9			2.7	4.7	2.0	8.2	10.0														
	NaOH	4.0	2.2	0.7			3.8	5.5	2.9	9.3	12.6														
		6.0	4.2	2.6			5.5	7.1	4.6	10.6	16.6														
		8.0	5.5	4.2			6.2	7.7	5.5	12.3	20.0														
		10.0	7.5	5.7			7.5	8.7	7.0	12.7	21.1														
MX 80	Calcium chloride	5.0	6.6	18.2	22.8				18.1	20.1		25.4			30.7	29.6	30.0	29.4	29.3						
KWK	$CaCl_2$		19.0	21.4	24.5				23.2	24.7		29.1			34.2	33.3	34.0	33.1	30.9						
Crusher run			19.4	22.0	26.0				24.4	25.6		28.9			33.5	32.4	33.0	33.5	33.0						
MX 80		10.0	15.4	31.9	38.2				35.6	35.6		42.9			51.6	48.1	48.8	49.2	49.2						
KWK			36.2	38.4	43.9				45.2	43.9		48.0			56.4	54.2	56.4	55.0	53.1						
Crusher run			32.8	34.8	41.6				43.3	44.2		46.2			56.0	51.6	52.5	52.7	52.7						
MX 80	Magnesium chloride	5.0	13.7	16.8	20.1				12.8	15.7		24.6			26.5	25.7	26.1	26.8	25.7						
KWK	$MgCl_2$		14.3	16.3	20.8				13.9	16.3		21.4			27.4	28.0	27.2	26.9	24.3						
Crusher run			14.1	16.3	20.7				13.2	15.9		22.0			25.3	25.3	28.9	24.4	23.8						
MX 80		10.0	21.4	24.0	29.1				26.8	28.4		32.6			40.3	35.7	37.9	35.7	36.6						
KWK			22.8	25.4	27.9				26.5	27.6		34.6			43.2	39.3	38.8	39.0	38.8						
Crusher run			23.6	26.0	30.6				27.1	28.4		32.4			43.5	38.5	38.5	37.6	38.7						
MX 80	Zinc chloride	5.0	9.1	10.8	12.4				7.5	11.7		12.2			17.5	18.8	19.7	15.9	20.8						
KWK	$ZnCl_2$		15.5	17.0	19.9				13.7	17.4		19.6			18.1	24.7	25.6	23.4	25.2						
Crusher run			15.9	18.9	22.2				15.2	18.3		22.7			22.2	24.1	28.9	24.4	26.9						
MX 80		10.0	20.5	22.2	26.7				22.5	25.3		26.9			32.6	33.0	37.7	32.4	35.5						
KWK			22.4	28.5	32.0				26.3	28.3		29.2			33.1	37.5	40.8	36.2	38.8						
Crusher run			24.9	26.7	33.0				33.5	28.4		33.0			40.9	39.8	42.0	37.0	41.4						
MX 80	Manganese sulfate	5.0	8.6	11.1	13.3																				
KWK	$MnSO_4$		9.5	11.9	13.5																				
Crusher run			8.8	10.4	12.8																				
MX 80		10.0	9.5	12.1	14.3																				
KWK			9.0	11.8	10.2																				
Crusher run			9.5	12.0	13.8																				
MX 80	Phosphorus pentoxide	5.0	18.1	18.6		20.6			22.9	22.9	22.6	22.0	22.8												
KWK	P_2O_5		15.5	17.7		20.3			22.1	22.1	21.9	22.1	23.0												
Crusher run			13.4	15.2		18.3			18.7	20.0	20.3	20.5	20.5												
MX 80		10.0	31.7	33.3		38.8			42.3	42.5	41.6	43.4	46.0												
KWK			24.3	26.5		30.7			35.1	35.1	34.9	33.3	32.2												
Crusher run			30.4	32.4		36.1			41.4	42.0	42.0	42.9	40.3												
MX 80	Phosphorus pentachloride	5.0	11.1	13.3		19.0			21.5	21.9	22.6	23.0	19.9												
KWK	PCl_5		10.6	13.5		18.3			20.5	20.5	20.3	20.3	18.8												
Crusher run			9.5	13.0		18.7			20.5	20.9	22.0	21.1	19.8												
MX 80		10.0	10.1	14.5		20.7			22.7	21.6	22.2	22.9	21.6												
KWK			12.7	14.0		20.0			21.5	20.2	21.1	21.5	20.8												
Crusher run			12.5	12.5		17.9			19.3	19.0	19.0	19.7	17.9												
MX 80	Potassium hydroxide	5.0	3.1	4.4		7.3			8.2	8.0	8.6	8.8	8.0												
KWK	KOH		3.8	5.0		8.4			9.1	9.7	10.2	10.2	8.8												
Crusher run			4.8	6.2		8.6			9.9	10.8	11.0	10.4	10.1												
MX 80		10.0	5.3	8.1		13.0			15.9	15.0	16.5	16.1	15.7												
KWK			7.2	7.9		12.9			14.9	14.9	14.9	16.0	14.7												
Crusher run			6.1	9.4		14.0			17.1	17.1	17.1	17.1	16.2												

* Per cent admixture (deliquescent) based on dry weight of bentonite.



INCREASE IN MOISTURE WITH TIME

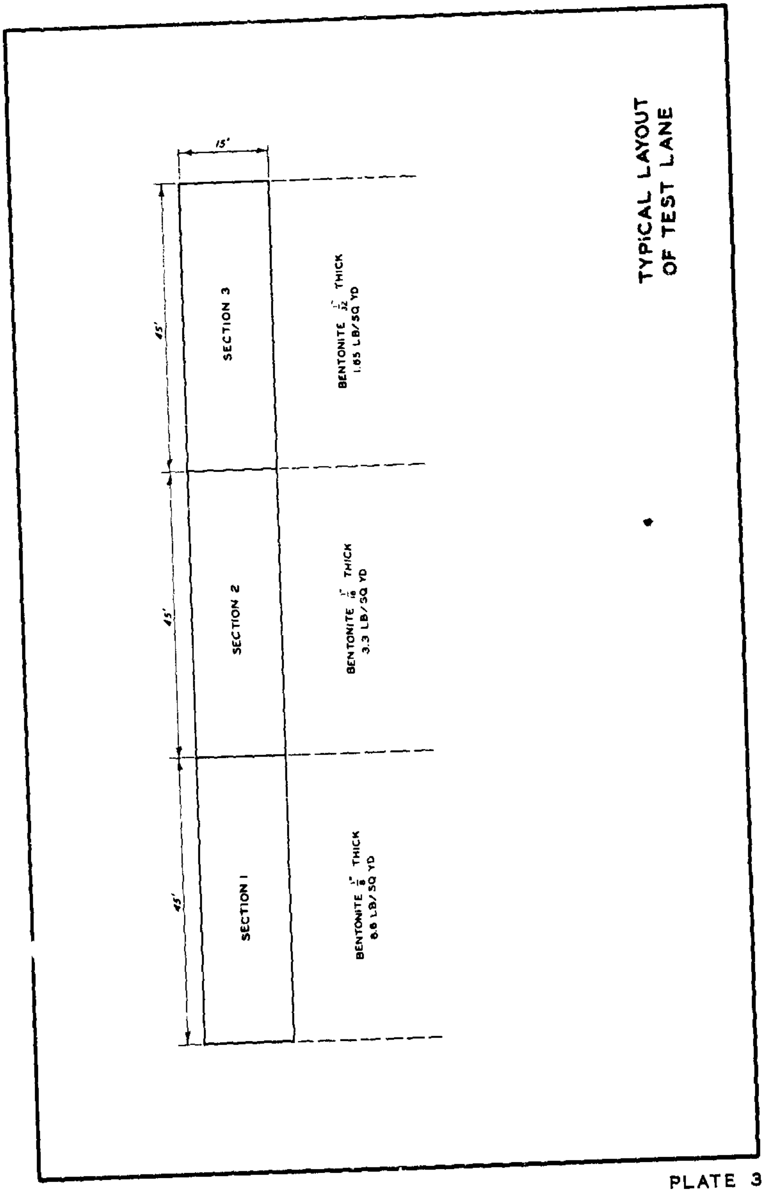
PLATE I



EFFECT OF ADMIXTURE ON ATTERBERG LIMITS

LEAN CLAY SOIL

PLATE 2



TYPICAL LAYOUT OF TEST LANE

PLATE 3